CLAIMS

What is claimed is:

1. A method for producing a single-crystal $M^{III}N$ article comprising the steps of:

(a) providing a template material having an epitaxial-initiating growth surface;

(b) sputtering a Group III metal target in a plasma-enhanced environment to produce a Group III metal source vapor;

(c) combining the Group III metal source vapor with a nitrogen-containing gas to produce a reactant vapor species comprising Group III metal and nitrogen;

(d) depositing the reactant vapor species on the growth surface to produce a single-crystal $M^{III}N$ layer thereon; and

(e) removing the template material, thereby providing a free-standing, single-crystal $M^{III}N$ article having a diameter of approximately 0.5 inch or greater and a thickness of approximately 50 microns or greater.

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2. The method according to claim 1 wherein the template material comprises a component selected from the group consisting of sapphire, silicon, silicon carbide, diamond, lithium gallate, lithium aluminate, ScAlMg, zinc oxide, spinel, magnesium oxide, gallium arsenide, glass, tungsten, molybdenum, hafnium, hafnium nitride, zirconium, zirconium nitride, carbon, silicon-on-insulator,

carbonized silicon-on-insulator, carbonized silicon-on-silicon, and gallium nitride.

3. The method according to claim 1 wherein the template material is selected from the group consisting of conductive substrates, insulating substrates, semi-insulating substrates, twist-bonded substrates, compliant substrates, or patterned substrates.

4. The method according to claim 1 wherein the template material has a thermal coefficient of expansion substantially equal to the $M^{III}N$ layer.

5. The method according to claim 1 wherein the template material has a diameter of approximately 0.5 inch or greater.

6. The method according to claim 1 wherein the Group III metal target comprises a component selected from the group consisting of gallium, indium, aluminum, and binary, ternary, and quaternary alloys and compounds thereof.

7. The method according to claim 1 wherein the nitrogen-containing gas includes species selected from the group consisting of diatomic nitrogen, atomic nitrogen, nitrogen ions, partially ionized nitrogen, ammonia, nitrogen-containing compounds, and combinations thereof.

8. The method according to claim 1 wherein the reactant vapor species is deposited directly on the template material.

9. The method according to claim 1 comprising the step of depositing an intermediate layer on the template material prior to depositing the reactant vapor species.

10. The method according to claim 9 wherein the intermediate layer comprises a material selected from the group consisting of GaN, AlN, InN, ZnO, SiC, and alloys thereof.

11. The method according to claim 9 wherein the intermediate layer comprises SiO2, Si_xN_y, diamond, lithium gallate, lithium aluminate, zinc oxide, spinel, magnesium oxide, gallium arsenide, tungsten, molybdenum, hafnium, hafnium nitride, zirconium, zirconium nitride, and carbon.

12. The method according to claim 9 wherein the intermediate layer is deposited by causing lateral epitaxial overgrowth of the intermediate layer on the growth surface.

13. The method according to claim 9 wherein the intermediate layer comprises more than one layer.

14. The method according to claim 9 wherein the intermediate layer is deposited by a technique selected from the group consisting of physical vapor deposition, sputtering, molecular beam epitaxy, atmospheric chemical vapor deposition, low pressure chemical vapor deposition, plasma-enhanced chemical vapor deposition, metallorganic chemical vapor deposition, evaporation, sublimation, and hydride vapor phase epitaxy.

15. The method according to claim 9 wherein the template material is removed by a technique selected from the group consisting of polishing, chemomechanical polishing, laser-induced liftoff, cleaving, wet etching, and dry etching.

16. The method according to claim 1 comprising the step of doping the $M^{III}N$ layer.

17. The method according to claim 1 wherein the $M^{III}N$ layer is formed at a growth rate of approximately 10 microns/hour or greater.

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18. The method according to claim 1 wherein the $M^{III}N$ article is provided in a form selected from the group consisting of intrinsic $M^{III}N$, doped $M^{III}N$, and $M^{III}N$ alloys and compounds containing greater than 50% M^{III} and N.

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19. The method according to claim 1 wherein the $M^{III}N$ article has a diameter of approximately 2 inches or greater and a thickness of approximately 1 mm or greater.

20. The method according to claim 1 wherein the template material is removed by a removal technique selected from the group consisting of polishing, chemomechanical polishing, laser-induced liftoff, cleaving, wet etching, and dry etching.

21. The method according to claim 1 comprising the step of cutting a wafer from the $M^{III}N$ article.

22. The method according to claim 1 comprising the step of preparing a surface of the $M^{III}N$ article for epitaxial growth thereon.

23. The method according to claim 1 comprising the step of depositing an epitaxial layer on the $M^{III}N$ article.

24. The method according to claim 1 comprising the step of forming a device on the $M^{III}N$ article.

25. The method according to claim 1 comprising the step of using the single-crystal $M^{III}N$ layer as a seed crystal and depositing additional reactant vapor species comprising the Group III metal

and nitrogen on the $M^{III}N$ layer to produce a bulk, homoepitaxially grown $M^{III}N$ article.

26. The method according to claim 25 wherein the bulk $M^{III}N$ article is deposited by a technique selected from the group consisting of physical vapor deposition, sputtering, molecular beam epitaxy, atmospheric chemical vapor deposition, low pressure chemical vapor deposition, plasma-enhanced chemical vapor deposition, metallorganic chemical vapor deposition, evaporation, sublimation, and hydride vapor phase epitaxy.

27. The method according to claim 25 comprising the step of cutting a wafer from the bulk, homoepitaxially grown $M^{III}N$ article.

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28. The method according to claim 27 comprising the step of preparing a surface of the wafer for epitaxial growth thereon.

29. The method according to claim 28 comprising the step of depositing an epitaxial layer on the wafer.

30. The method according to claim 27 comprising the step of forming a device on the wafer.

31. The method according to claim 1 wherein the template material is not removed, and the $M^{III}N$ layer is used as a seed crystal for the

~~deposition thereon of additional reactant vapor species comprising the Group III and nitrogen, thereby producing a bulk, homoepitaxially grown $M^{III}N$ article.~~

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~~32. The method according to claim 31 wherein the bulk $M^{III}N$ article is deposited by a technique selected from the group consisting of physical vapor deposition, sputtering, molecular beam epitaxy, atmospheric chemical vapor deposition, low pressure chemical vapor deposition, plasma-enhanced chemical vapor deposition, metallorganic chemical vapor deposition, evaporation, sublimation, and hydride vapor phase epitaxy.~~

~~33. The method according to claim 31 comprising the step of cutting a wafer from the bulk $M^{III}N$ article.~~

34. The method according to claim 33 comprising the step of preparing a surface of the wafer for epitaxial growth thereon.

35. The method according to claim 34 comprising the step of depositing an epitaxial layer on the wafer.

36. The method according to claim 33 comprising the step of forming a device on the wafer.

37. A bulk single-crystal $M^{III}N$ article produced according to the method of claim 1 wherein the article has a diameter of approximately 0.5 inch to approximately 12 inches and a thickness of approximately 50 microns or greater.

38. A single-crystal $M^{III}N$ article produced according to the method of claim 1, wherein the article is in wafer form having a thickness ranging from approximately 50 microns to approximately 1mm.

39. A single-crystal $M^{III}N$ article produced according to the method of claim 1, wherein the article is in boule form having a diameter of approximately 2 inches or greater and a thickness ranging from approximately 1mm to greater than approximately 100mm.

40. A method for producing a single-crystal $M^{III}N$ article comprising the steps of:

(a) providing a template material having an epitaxial-initiating growth surface;

(b) using a sputtering apparatus comprising a non-thermionic electron/plasma injector assembly to produce a Group III metal source vapor from a Group III metal target;

(c) combining the Group III metal source vapor with a nitrogen-containing gas to produce a reactant vapor species comprising Group III metal and nitrogen; and

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(d) depositing the reactant vapor species on the growth surface to produce an single-crystal $M^{III}N$ layer thereon.

41. The method according to claim 40 wherein the injector assembly comprises a plurality of hollow cathode injectors disposed in fluid communication with a gas source, each injector including an orifice communicating with a sputtering chamber.

42. The method according to claim 40 wherein the injector assembly comprises:

(a) a main body having a generally annular orientation with respect to a central axis and including a process gas section and a cooling section, the process gas section defining a process gas chamber and the cooling section defining a heat transfer fluid reservoir; and

(b) a plurality of gas nozzles removably disposed in the main body in a radial orientation with respect to the central axis and in heat transferring relation to the heat transfer fluid reservoir, each gas nozzle providing fluid communication between the process gas chamber and a region exterior to the main body.

43. The method according to claim 40 comprising the step of removing the template material, thereby providing a free-standing, single-crystal $M^{III}N$ article.

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44. A bulk single-crystal $M^{III}N$ article produced according to the method of claim 40 wherein the article has a diameter of approximately 0.5 inch or greater and a thickness of approximately 50 microns or greater.

45. A single-crystal $M^{III}N$ article produced according to the method of claim 40, wherein the article is in wafer form having a thickness ranging from approximately 50 microns to approximately 1mm.

46. A single-crystal $M^{III}N$ article produced according to the method of claim 40, wherein the article is in boule form having a diameter of approximately 2 inches or greater and a thickness ranging from approximately 1mm to greater than approximately 100mm.

47. A single-crystal $M^{III}N$ article produced according to the method of claim 40 at a growth rate greater than approximately 10 microns/hour.

48. A highly-oriented polycrystalline Group III nitride material having an elongate surface and a plurality of grain boundaries oriented substantially normal to the elongate surface, wherein thermal conductivity is enhanced through the thickness of the material in a direction substantially normal to the elongate surface and is impeded in a direction substantially parallel to the elongate

surface, and wherein the material is substantially transparent to radiative energy in the infrared or microwave spectrum along the direction substantially normal to the elongate surface.

49. The material according to claim 48 having an aluminum nitride composition.

50. The material according to claim 48 having a gallium nitride composition.

51. The material according to claim 48 wherein the material has a thickness of at least approximately 50 μm.

52. A window adapted to transmit radiative energy in the infrared and/or microwave spectra comprising:

(a) a metallic frame; and

(b) a polycrystalline Group III nitride material supported by the metallic frame, the material including opposing outer and inner elongate surfaces and a plurality of grain boundaries oriented substantially normal to the elongate surfaces, wherein thermal conductivity is enhanced through the thickness of the material in a direction substantially normal to the elongate surfaces and is impeded in a direction substantially parallel to the elongate surfaces.

53. The window according to claim 52 wherein the material is aluminum nitride.

54. The window according to claim 52 wherein the material is gallium nitride.

55. The window according to claim 52 wherein the material has a thickness of at least approximately 50 microns.

56. A method for producing a window adapted to transmit radiative energy in the infrared and/or microwave spectra comprising the steps of:

(a) providing a negatively-biased target cathode including a target material in a sealed chamber;

(b) providing a metallic frame in the chamber spaced at a distance from the target cathode;

(c) applying an operating voltage to the target cathode to produce an electric field within the chamber;

(d) providing a magnetron assembly in the chamber to produce a magnetic field within the chamber;

(e) providing a negatively-biased, non-thermionic electron/plasma injector assembly between the target cathode and the metallic frame to create an intense plasma proximate to the target cathode;

(f) introducing a gas into the chamber to provide an environment for generating a plasma medium; and

(g) causing a portion of the target material to be sputtered and transported through the plasma medium toward the metallic frame.

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